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ABSTRACT

Limited systematic instruction was provided for two third-grade classes on a calculator-assisted approach to solving selected types of simple open addition and subtraction sentences involving three-place whole-number addends, moving from a Guess-and-Test procedure to more direct and efficient sentential transformations. Pupils exhibited a relatively high level of computational accuracy in their use of minicalculators or hand-held electronic calculators (94%) but substantially lower levels of proficiency in providing mathematically correct solutions for "taught" and related "untaught" open-sentence types (ranging from 66% to 23%). Serious questions are raised regarding the appropriateness for young children of certain instructional approaches to the solution of simple open addition and subtraction sentences. (Author/SD)

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Project Paper 76-3

Calculator-influenced Explorations in School Mathematics: A Further Investigation of Third-grade Pupils' Performance on Open Addition and Subtraction Sentences

by

J. F. Weaver

Report from the Project on

ANALYSIS OF MATHEMATICS INSTRUCTION

Wisconsin Research and Development
Center for Cognitive Learning

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ABSTRACT

Limited systematic instruction was provided for two third-grade classes on a unary-operator calculator-assisted approach to solving selected types of simple open addition and subtraction sentences involving three-place whole-number addends, moving from a Guess-and-Test procedure to more direct and efficient sentential transformations.

Pupils exhibited a relatively high level of computational accuracy in their use of mini or hand-held electronic calculators (94%) but substantially lower levels of proficiency in providing mathematically correct solutions for "taught" and related "untaught" open-sentence types (ranging from 66% to 23%).

Serious questions are raised regarding the appropriateness for young children of certain instructional approaches to the solution of simple open addition and subtraction sentences.

PURPOSE

It was the intent of this investigation to analyze third-grade pupils' performance on (1) selected types of open addition and subtraction sentences (three-place addends) following limited systematic instruction of a particular kind and (2) the symmetric counterparts of those sentence types without systematic instruction thereon.

BACKGROUND

Earlier research identified factors associated with young children's performance on various types of simple open addition and subtraction sentences within the domain of basic number facts (Weaver, 1971, 1972, 1973) and gave impetus to replication or extension (including multiplication and division sentences) by Grouws (1972, 1974), Grouws & Good (1976), McMaster (1975), and Montague (1971). Data for the further investigation reported here were collected early in 1976 within the context of broader ongoing explorations pertaining to sentential transformations and the use of hand-held electronic calculators in school mathematics instruction (Weaver, 1976a).

METHOD

For each of two third-grade classes this investigator devoted seven 30-minute instructional periods--one per week during each of seven consecutive weeks--to work associated with three-place addends and the open-sentence forms and types identified in Table 1. No instruction was included on the open-sentence forms and types identified in Table 2, however.

The instructional approach for each open-sentence form/type emphasized unary operators (but not formally named as such), first symbolized as in Figure 1 and solved (when whole-number solutions existed) by successive approximations and corrections--a Guess-and-Test procedure. This then was replaced by a more direct and efficient approach illustrated by Figure 2, in which the given sentence A was transformed into an equivalent sentence B whose solution also was the solution for A. Finally, instruction was directed to the conventional or standard open-sentence notation(s) and transformation(s) identified in Table 3, interpreted in terms of unary operators rather than binary operations.

Much of the work with open sentences was done in association with orally described and imagined physical situations; i.e., within the context of "word problems." Also, instruction was calculator-assisted (rather than calculator-

TABLE 1

WHOLE-NUMBER OPEN-SENTENCE TYPES

FORM	EXISTENCE OF A WHOLE-NUMBER SOLUTION	
1: $\square + Q = R$	1.1: YES $(R > Q)$	1.2: NO $(R < Q)$
2: $P + \square = R$	2.1: YES $(R > P)$	2.2: NO $(R < P)$
3: $\square - Q = R$	3.1 YES[a]	
4: $P - \square = R$	4.1: YES $(R < P)$	4.2: NO $(R > P)$

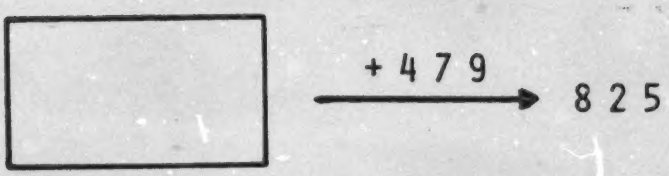
[a]REGARDLESS OF THE RELATIVE VALUES OF WHOLE NUMBERS Q AND R, THE SOLUTION IS NECESSARILY A WHOLE NUMBER.

TABLE 2

SYMMETRIC FORMS OF WHOLE-NUMBER OPEN-SENTENCE TYPES

FORM	EXISTENCE OF A WHOLE-NUMBER SOLUTION	
5: $R = \square + Q$	5.1: YES $(R > Q)$	5.2: NO $(R < Q)$
6: $R = P + \square$	6.1: YES $(R > P)$	6.2: NO $(R < P)$
7: $R = \square - Q$	7.1: YES[a]	
8: $R = P - \square$	8.1: YES $(R < P)$	8.2: NO $(R > P)$

[a]REGARDLESS OF THE RELATIVE VALUES OF WHOLE NUMBERS Q AND R, THE SOLUTION IS NECESSARILY A WHOLE NUMBER.



GUESS TEST

FIGURE 1. SAMPLE GUESS-AND-TEST WORKSHEET.

FIGURE 2. A MORE DIRECT AND EFFICIENT APPROACH TO REPLACE THE GUESS-AND-TEST PROCEDURE.

TABLE 3

OPEN-SENTENCE TRANSFORMATIONS

GIVEN FORM	SOLUTION FORM
1: $\square + Q = R$	1′: $R - Q = \square$
2: $P + \square = R$	2′: $R - P = \square$
3: $\square - Q = R$	3′: $R + Q = \square$[a]
4: $P - \square = R$	4′: $P - R = \square$

[a] $Q + R = \square$ ALSO SUGGESTED BY PUPILS.

modulated or calculator-based [Weaver, 1976b]) in the sense that all computations when solving open sentences or verifying their solutions were done with mini or hand-held electronic calculators.

Eight six-item tests were constructed, reflecting the conditions identified in Table 4. (See Appendix A and Appendix B for specific test items.)

1. One week after the end of systematic instruction each pupil took one of the four tests 1A or 1B or 1C or 1D. Each test item (open sentence) that had a whole-number solution was to be transformed into an equivalent solvable form and rewritten in that form with its solution. For instance, the item

$$364 + \square = 750$$

was to be rewritten as $750 - 364 = \boxed{386}$. If a given sentence had no whole-number solution (e.g., $479 - \square = 802$), the pupil was to respond by marking X for that item. Electronic calculators were used for all computations.

2. One week later each pupil took one of the four tests 2A or 2B or 2C or 2D. Each test item (open sentence) was to be solved in any way elected by the pupil and then simply rewritten--along with its solution--in the same form as given. No transformations were demanded. For instance, the item

$$972 = 148 + \square$$

simply would be rewritten as $972 = 148 + \boxed{824}$. As before: if a given sentence had no whole-number solution, the pupil was to mark X for that item; also, calculators were used for all computations.

RESULTS

Tests were scored in several different ways to provide various kinds of information pertaining to the 44 pupils who contributed data.

Accuracy of calculator use. Each pupil response that was expressed as a completed number sentence was scored "1" or "0" on the basis of its computational correctness, regardless of its conceptual correctness vis-à-vis the given open sentence. For instance, given the item

$$364 + \square = 750$$

a pupil response of $750 + 364 = \boxed{1114}$ was scored "1" rather than "0" since it was a computationally correct statement, albeit a conceptually incorrect solution for the given open sentence.

On this basis, approximately 94% of all pupils' completed number sentences were computationally correct--both for tests 1A,1B,1C,1D and 2A,2B,2C,2D.

TABLE 4

DISTRIBUTION OF ITEM TYPES AMONG TESTS

ITEM TYPE[a]	ITEM NUMBER				ITEM TYPE[a]	ITEM NUMBER			
	TEST 1A	TEST 1B	TEST 1C	TEST 1D		TEST 2A	TEST 2B	TEST 2C	TEST 2D
1.1	1	4	5	6	5.1	5	6	1	4
2.1	4	1	2	2	6.1	2	2	4	1
3.1	2[b]	3[b]	1[c]	4[c]	7.1	1[c]	4[c]	2[b]	3[b]
4.1	5	6	3	1	8.1	3	1	5	6
1.2	6			3	5.2		3	6	
2.2		5	4		6.2	4			5
4.2	3	2	6	5	8.2	6	5	3	2

[a]SEE TABLES 1 AND 2 FOR CHARACTERIZATIONS OF ITEM TYPES.

[b] $R < Q$

[c] $R > Q$

Level of mathematical performance. This principal scoring classification embraces several categories of response.

1. For items having whole-number solutions, a response had to be conceptually and computationally correct to be scored "1" as mathematically correct. If such a response were in the precise form specified by the directions for a particular set of tests, that response also was termed a criterion response; otherwise, it was a "non-criterion" mathematically correct response. For instance:

a. Given the Test 1B item $653 - \square = 298$, each of the two responses $653 - 298 = \boxed{355}$ and $298 + \boxed{355} = 653$, for instance, is mathematically correct. The former also is a criterion response for that test; the latter is not.

b. Given the Test 2C item $968 = \square + 675$, each of the two responses $968 = \boxed{293} + 675$ and $968 - 675 = \boxed{293}$, for instance, is mathematically correct. The former also is a criterion response for that test; the latter is not.

2. For items having no whole-number solutions, the only correct response (scored "1") was X. To the item $463 = 792 + \square$, for instance, a response of $463 = 792 + \boxed{-329}$ was scored "0" since it does not make explicit that the given sentence has no whole-number solution. (A nontrivial number of third-grade pupils are insensitive to the fact that "-329" is not a whole number.)

Based upon the preceding scoring guidelines, an overview of pupil performance is presented in Table 5. The "Test 1" column was generated from a pooling of data across Tests 1A, 1B, 1C and 1D. Similarly, the "Test 2" column was generated from a pooling of data across Tests 2A, 2B, 2C and 2D.

The Table 5 data suggest that pupil performance is far from uniform with respect to the variables involved and that such performance should be analyzed in greater detail. This was done independently for each of two sets of items: those involving sentences having whole-number solutions, and those involving sentences having no whole-number solution. Any particular consideration of results summarized in Table 5 is embedded within these more detailed analyses which follow.

TABLE 5

OVERVIEW OF PUPIL PERFORMANCE

SENTENCES HAVING WHOLE-NUMBER SOLUTIONS (4-ITEM SUBTEST)	MEAN	
	TEST 1	TEST 2
CRITERION RESPONSE[a]	1.89	.77
OTHER MATHEMATICALLY CORRECT RESPONSES[a]	.23	1.00
TOTAL MATHEMATICALLY CORRECT RESPONSES[a]	2.11	1.77
SENTENCES WITH NO WHOLE NUMBER SOLUTION (TRANSLATED TO 4-ITEM METRIC)	1.41	1.50

[a]COMPUTATIONALLY AND CONCEPTUALLY CORRECT.

Sentence having whole-number solutions. Each of the four versions of Test 1 (Tests 1A, 1B, 1C, 1D) included a four-item subtest consisting of one exemplar of each of these item types: 1.1, 2.1, 3.1, 4.1 (Table 4). Likewise, each of the four versions of Test 2 (Tests 2A, 2B, 2C, 2D) included a four-item subtest consisting of one exemplar of each of these item types: 5.1, 6.1, 7.1, 8.1 (Table 4).

As indicated in Table 5, the mean number of mathematically correct responses on these four-item subtests was 2.11 in the case of Test 1 and 1.77 in the case of Test 2. We shall disregard at this time the differences among "criterion" and "other" response categories and consider only the indicated means based on the total number of mathematically correct responses, along with the partitioning of these means by item-type as summarized in Table 6.

Table 7 suggests that:

1. The shapes of the distribution of subtest scores for Test 1 and Test 2 were somewhat different.

2. The mean of the subtest scores on Test 1 (2.11) was significantly greater than the mean of the subtest scores on Test 2 (1.77). [The existence of a directional difference was conjectured on the basis of findings from previous research.]

Table 8 provides evidence that:

1. The pupils' performance levels differed significantly among item types on each of the two four-item subtests [Cochran Q's].

2. There was no support [McNemar χ^2's] for the a priori conjecture that performance on each Test 1 item type would be significantly higher than performance on its corresponding Test 2 item type.

Table 9 suggests that pupils' patterns of response to pairs of corresponding items differed in degree of consistency across item types.

Sentences having no whole-number solution. Each of the four versions of Test 1 included a two-item subtest consisting of one exemplar of each of these item types: either 1.2 or 2.2, and 4.2. Similarly, each of the four versions of Test 2 included a two-item subtest consisting of one exemplar of each of these item types: either 5.2 or 6.2, and 8.2. [Table 4]

Data (not included here) gave no cause to believe that performance on these items was differentially influenced by item type, either between or within subtests. However, Table 5 suggests lower relative performance compared with items having whole-number solutions.

TABLE 6

MEAN MATHEMATICALLY CORRECT RESPONSES
ON SENTENCES HAVING WHOLE-NUMBER SOLUTIONS

PLACEHOLDER POSITION	KIND OF SENTENCE		Σ
	+	-	
TEST 1			
☐ IN P-POSITION	.66	.36	1.02
☐ IN Q-POSITION	.64	.45	1.09
Σ	1.30	.82	2.11
TEST 2			
☐ IN P-POSITION	.50	.23	.73
☐ IN Q-POSITION	.64	.41	1.05
Σ	1.14	.64	1.77

TABLE 7

FURTHER ANALYSIS OF PUPIL PERFORMANCE ON ITEMS INVOLVING SENTENCES HAVING WHOLE-NUMBER SOLUTIONS

TEST 1	
SCORE[a]	F
4	2
3	20
2	9
1	7
0	6
N	44
M	2.11
s	1.17

TEST 2	
SCORE[a]	F
4	4
3	9
2	13
1	9
0	9
N	44
M	1.77
s	1.26

TEST 1 - TEST 2	
SCORE[b]	F
2	6
1	14
0	16
-1	5
-2	3
N	44
M	.341
s	1.077
s_M	.162
T	2.099[c]

[a]NUMBER OF MATHEMATICALLY CORRECT RESPONSES.

[b]DIFFERENCE SCORE.

[c] $.01 < p < .025$ FOR A ONE-TAILED TEST.

TABLE 8

SUMMARY OF ADDITIONAL STATISTICAL TESTS INVOLVING ITEMS HAVING WHOLE-NUMBER SOLUTIONS

STATISTICAL TEST[a]	COMPUTED VALUE	SIGNIFICANCE LEVEL
COCHRAN Q TEST		
A. FOR 1.1, 2.1, 3.1 AND 4.1 ITEMS	12.179	$.001 < P < .01$
B. FOR 5.1, 6.1, 7.1 AND 8.1 ITEMS	19.358	$.001 > P$
MCNEMAR x^2 TEST		
C. FOR 1.1 VS. 5.1 ITEMS	2.333	$.05 < P < .10$[c]
D. FOR 2.1 VS. 6.1 ITEMS	d	
E. FOR 3.1 VS. 7.1 ITEMS	2.500[b]	$.05 < P < .10$[c]
F. FOR 4.1 AND 8.1 ITEMS	.071[b]	$.35 < P < .40$[c]

[a]SEE TABLES 1 AND 2 FOR CHARACTERIZATIONS OF ITEM TYPES.

[b]YATES' CORRECTION FOR CONTINUITY WAS USED.

[c]ONE-TAILED TEST.

[d]OBSERVED DIFFERENCE = 0; x^2 NOT COMPUTED.

TABLE 9

RESPONSE CONSISTENCY ON SYMMETRIC FORMS OF ITEMS HAVING WHOLE-NUMBER SOLUTIONS

ITEM TYPES[a]	PERCENT OF PUPILS		
	BOTH RESPONSES CORRECT	NEITHER RESPONSE CORRECT	ONLY ONE RESPONSE CORRECT
1.1 AND 5.1	34.1	18.2	47.7
2.1 AND 6.1	50.0	22.7	27.2
3.1 AND 7.1	18.2	59.1	22.7
4.1 AND 8.1	27.2	40.9	31.8

[a]SEE TABLES 1 AND 2 FOR CHARACTERIZATIONS OF ITEM TYPES.

Discussion and Implications

Pupils involved in this exploration had encountered previously in their ongoing mathematics program exemplars of open-sentence types 1.1, 2.1, 3.1, 4.1 (Table 1) but only within the context of "basic facts." Although attention had been given to relationships between addition and subtraction, pupils solved open sentences without explicitly changing and rewriting them in equivalent forms.

The transformation approach stressed in this exploration was in fact "new learning" for the pupils. Its effectiveness--judging from the results presented previously--left much to be desired. Although pupils demonstrated a high degree of accuracy in using calculators as a means of minimizing any preoccupation with computation, the resulting relatively uninhibited focus upon conceptualizations and relationships was not as productive as had been hoped. This brief interim report makes no attempt to consider all facets of this condition. (That remains for a subsequent more comprehensive document.) Rather, attention is given at this time only to the crucial problem of effecting for open sentences having whole-number solutions (types 1.1, 2.1, 3.1, 4.1 of Table 1) the transformations identified in Table 3.

Consider, for instance, these two transformation forms and an exemplar of each:

1. $\square + q = r \rightarrow r - q = \square$ and $\square + 397 = 581 \rightarrow 581 - 397 = \square$

3. $\square - q = r \rightarrow r + q = \square$ and $\square - 486 = 275 \rightarrow 275 + 486 = \square$

During the course of the exploratory instruction a concerted attempt was made to handle both such transformations in terms of <u>one</u> idea: "doing-and-undoing." In general, if $\nabla\, q$ and $\Delta\, q$ are inverse operators, $n \nabla q \Delta q = n$; or, $n \nabla q = r \rightarrow r \Delta q = n$. This one <u>idea</u>--without the symbolism just used--was stressed, with an emphasis upon $+\, q$ and $-\, q$ as "opposites" of each other. The opposite of $+\, q$ (doing) is $-\, q$ (undoing), and the opposite of $-\, q$ (doing) is $+\, q$ (undoing).

If this idea is comprehended, neither transformation (1 nor 3) should be any harder or easier than the other. But Table 10--an augmentation of previously presented information--suggests quite clearly that relatively few pupils apparently comprehended and used the unifying idea that was stressed. The difference in performance levels--66% correct vs. 36% correct--is highly significant statistically. Even the higher performance level is lower than

TABLE 10

CONTINGENCY TABLE FOR OPEN-SENTENCE TYPES 1.1 AND 3.1

(PERCENT OF PUPIL RESPONSES)

		□ - Q = R		TOTAL
		NOT CORRECT	CORRECT	
□ + Q = R	CORRECT	36%	30%	66%
	NOT CORRECT	27%	7%	34%
	TOTAL	64%	36%	100%

anticipated, and only 30% of the pupil responses were mathematically correct for both open-sentence types.

Now consider the remaining two transformations and an exemplar of each:

2. $p + \square = r \rightarrow r - p = \square$ and $379 + \square = 518 \rightarrow 518 - 379 = \square$

4. $p - \square = r \rightarrow p - r = \square$ and $468 - \square = 257 \rightarrow 468 - 257 = \square$

This pair of transformations cannot be approached directly through "doing-and-undoing" or any other simple, common idea. It is much more difficult, in fact, to generate transformations 2 and 4 logically (in a mathematical sense) than to generate transformations 1 and 3, and (I believe) to generate transformation 4 than transformation 2. In any event, the data of Table 6 suggest that pupils were better able--by one means or another--to cope with exemplars of 2 than with exemplars of 4: 64% correct responses vs. 45% correct responses.

Admittedly, the length and pacing of the instructional treatment, with no systematic reinforcement between weekly sessions, left much to be desired. But was that the principal reason for pupils' relatively low, differential performance levels? I doubt it.

It more likely may be the case that most third-grade pupils simply lack the mathematical maturity to profit from an approach to transformations that emphasizes certain properties and combinations thereof. Is such an approach too "formal," too "logical" at this stage of their mathematical development? It very well may be so, and we very well may need to search for or devise more informal, "intuitive" approaches that are sufficiently mature, however, to be effective with open sentences that involve numbers of the magnitude used in the present explorations.

Evidence from pupils' work with sentences having no whole-number solution and with "untaught" sentence types summarized in Table 2 gives further cause to question aspects of the instructional approach stressed in the present exploration.

Is it possible that some of our work with young children tends to be too mathematical, or too mathematically sophisticated, to have much meaning for them? If so, how can we modify our approaches to be "mathematically honest" at a less sophisticated or rigorous level? Even then, may we be pushing some things sooner and faster than there is any compelling need to do?

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Appendix A. Test 1 items.

Open sentence type		Test item			
Form	A whole number solution?	Test 1A	Test 1B	Test 1C	Test 1D
p + □ = r	Yes (r>p)	d) 364 + □ = 750	a) 248 + □ = 921	b) 184 + □ = 927	b) 436 + □ = 851
p + □ = r	No (r<p)		e) 729 + □ = 436	d) 745 + □ = 602	
□ + q = r	Yes (r>q)	a) □ + 657 = 986	d) □ + 316 = 895	e) □ + 176 = 831	f) □ + 537 = 921
□ + q = r	No (r<q)	f) □ + 578 = 325			c) □ + 605 = 124
p - □ = r	Yes (p>r)	e) 612 - □ = 154	f) 653 - □ = 298	c) 859 - □ = 293	a) 973 - □ = 296
p - □ = r	No (p<r)	c) 479 - □ = 802	b) 476 - □ = 810	f) 259 - □ = 512	e) 418 - □ = 642
□ - q = r	Yes (r>q)			a) □ - 385 = 432	d) □ - 259 = 763
□ - q = r	Yes (r<q)	b) □ - 583 = 241	c) □ - 529 = 174		

Administered 24 February 1976 to third-grade classes.

Appendix B. Test 2 items.

Open sentence type		Test item			
Form	A whole number solution?	Test 2A	Test 2B	Test 2C	Test 2D
r = p + □	Yes (r>p)	b) 972 = 148 + □	b) 815 = 463 + □	d) 705 = 346 + □	a) 912 = 284 + □
r = p + □	No (r<p)	d) 620 = 754 + □			e) 463 = 792 + □
r = □ + q	Yes (r>q)	e) 813 = □ + 167	f) 912 = □ + 573	a) 968 = □ + 675	d) 859 = □ + 361
r = □ + q	No (r<q)		c) 142 = □ + 650	f) 352 = □ + 587	
r = p - □	Yes (p>r)	c) 239 = 895 - □	a) 269 = 937 - □	e) 145 = 621 - □	f) 289 = 635 - □
r = p - □	No (p<r)	f) 521 = 295 - □	e) 624 = 481 - □	c) 820 = 497 - □	b) 801 = 467 - □
r = □ - q	Yes (r>q)	a) 423 = □ - 358	d) 736 = □ - 295		
r = □ - q	Yes (r<q)			b) 214 = □ - 538	c) 147 = □ - 592

Administered 2 March 1976 to third-grade classes.